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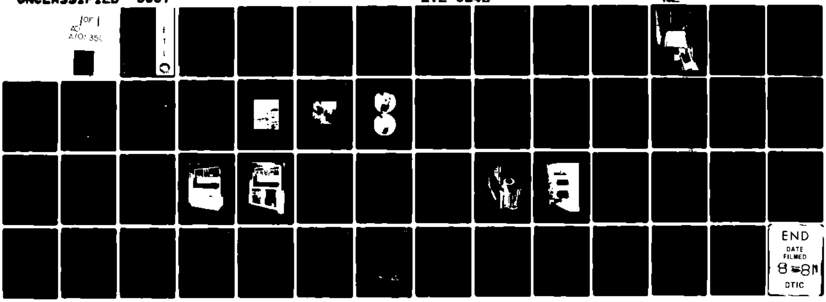

ETL-0246

LEVEL II

Pre-production model cartographic EBR system

AD A101350

P. F. Grosso

A. A. Tarnowski

Image Graphics, Inc.

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NOVEMBER 1980

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Prepared for

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ENGINEER TOPOGRAPHIC LABORATORIES
FORT BELVOIR, VIRGINIA 22060

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Pre-production Model Cartographic EBR System installed at the Hydrographic/Topographic Center in Washington, D.C. is a high speed, high resolution, recording system capable of plotting both lineal and raster data developed for the Defense Mapping Agency (DMA) to produce color separation film masters for maps, charts and high resolution satellite and aerial imagery from digital

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cartographic and image data on magnetic tape. The color separations are used to prepare press-ready printing plates for conventional multi-color printing presses for the printing of color charts and maps or to produce color composities of satellite imagery.

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PREFACE

The work described in this report was authorized by the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, 22060, under contract No. DAAG70-78-C-0188 and was conducted by Image Graphics, Inc. (IGI) under the direction of Patrick F. Grosso with Andrew A. Tarnowski serving as the Program Manager.

The contract was performed under the technical direction of the Automated Cartography Branch, Mapping Developments Division, U.S. Army Engineer Topographic Laboratories (USAETL) under the direction of Howard Carr. Fred Merkel served as the Contracting Officer's Technical Representative.

The following individuals at IGI made significant contributions to the success of this program.

Brian Anderson
John Breslawski
Eugene Gostomski
Steve Kerepesi
Michael Kirmaier
George Krampetz
Francis Reilly
John E. Turek
Robert Underwood

1.0 Introduction

During the last several years the Automated Cartography Branch (ACB), Mapping Developments Division (MDD), USAETL, at Fort Belvoir has been investigating the use of electron beam recording techniques to further the automation of map production.

Cartographic Electron Beam Recorders have been developed for the Defense Mapping Agency (DMA) (1-4), to produce aerospace, topographic and hydrographic charts, specialized high resolution electronic imagery and various other cartographic products.

A Cartographic EBR delivered to the Aerospace Center, St. Louis, Mo. in May, 1978 by Image Graphics, Inc., under a subcontract with the Synectics Corporation[(2)] is the principal cartographic output device from lineal input data of the Charting, Publishing and Air Facilities subsystems of the Automated Air Information Production System (AAIPS).

The present contract, reported on herein, was to design, fabricate, install and test a preproduction model of a Cartographic EBR System capable of plotting and recording on film from lineal and/or raster digital data bases.

The preproduction model Cartographic EBR System was installed at the DMA Hydrographic Topographic Center (HTC), Washington, D.C. and will be used to investigate the production of a variety of cartographic, micrographic, satellite and aerial image products by HTC government personnel.

IGI

2.0 Technical Discussion

2.1 General Description of Cartographic EBR System

The preproduction model Cartographic EBR System, shown in Figures 1 and 2, is a stand-alone, high performance electronic recording system which is capable of precision plotting (recording) high resolution imagery on various electron sensitive media. It is ideally suited for the automated production of computer generated maps; recording of high resolution sensor imagery; and numerous other high quality micrographics applications.

The Cartographic EBR System has several modes of operation which allow it to be used for the automated production of a variety of existing and new map and image products such as:

Minimap color separations

Continuous tone imagery from satellite and aerial reconnaissance sensors data

Radar imagery

Flight Information Publications (FLIP) Charts and Texts as back-up for DMAAC AAIPS Program

Computer generated micrographics (including symbols and characters of graphic arts quality)

Binary raster data

Run-length encoded raster data

High resolution image processing and enhancement

2.1.1 Modes of Operation

The Cartographic EBR System is designed to operate in any one or combinations of the following ways to produce maps or pictures of various sizes and formats up to a maximum of 8¼ x 5 inches.

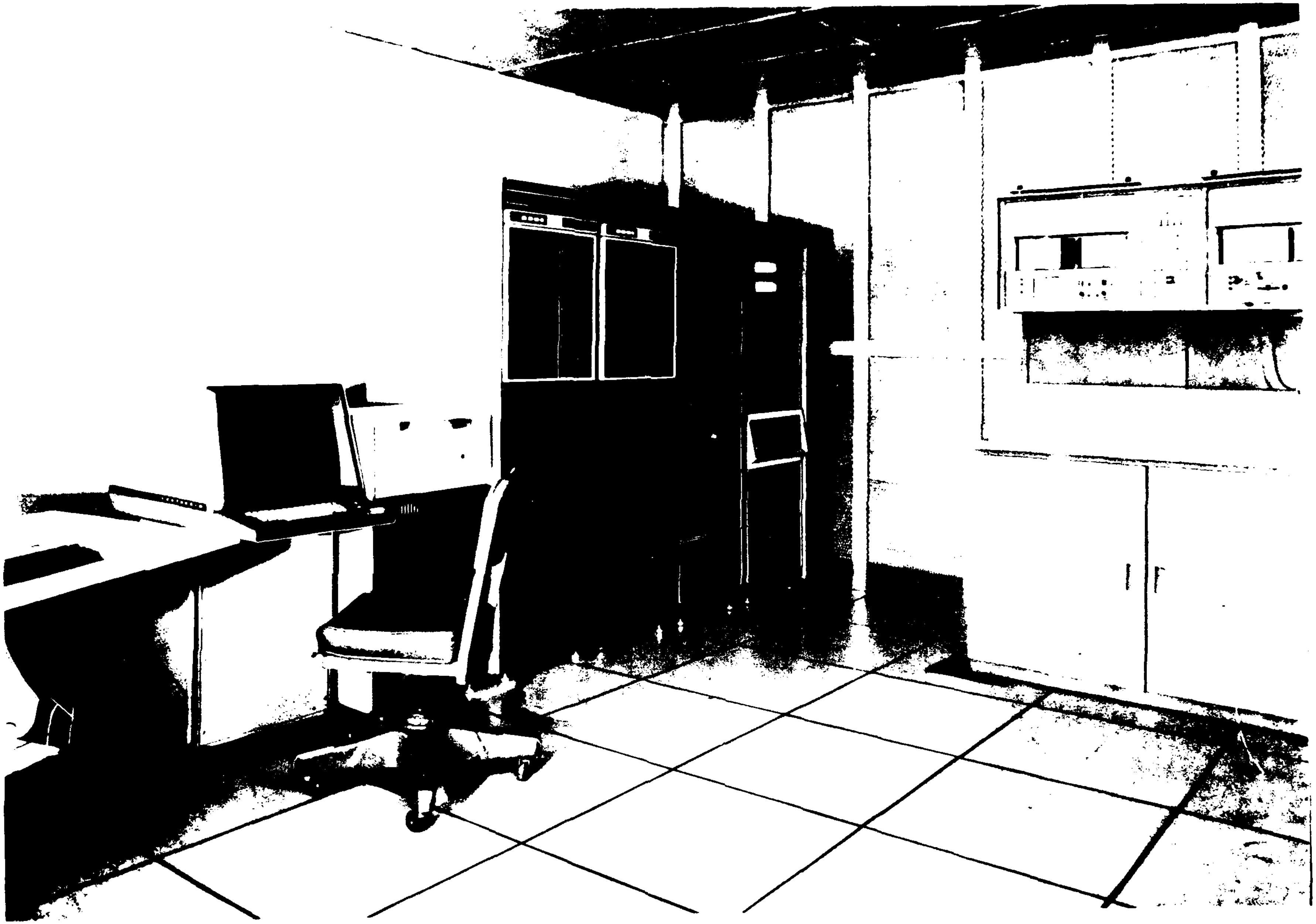

FIGURE 1 - PREPRODUCTION MODEL CARTOGRAPHIC EBR SYSTEM

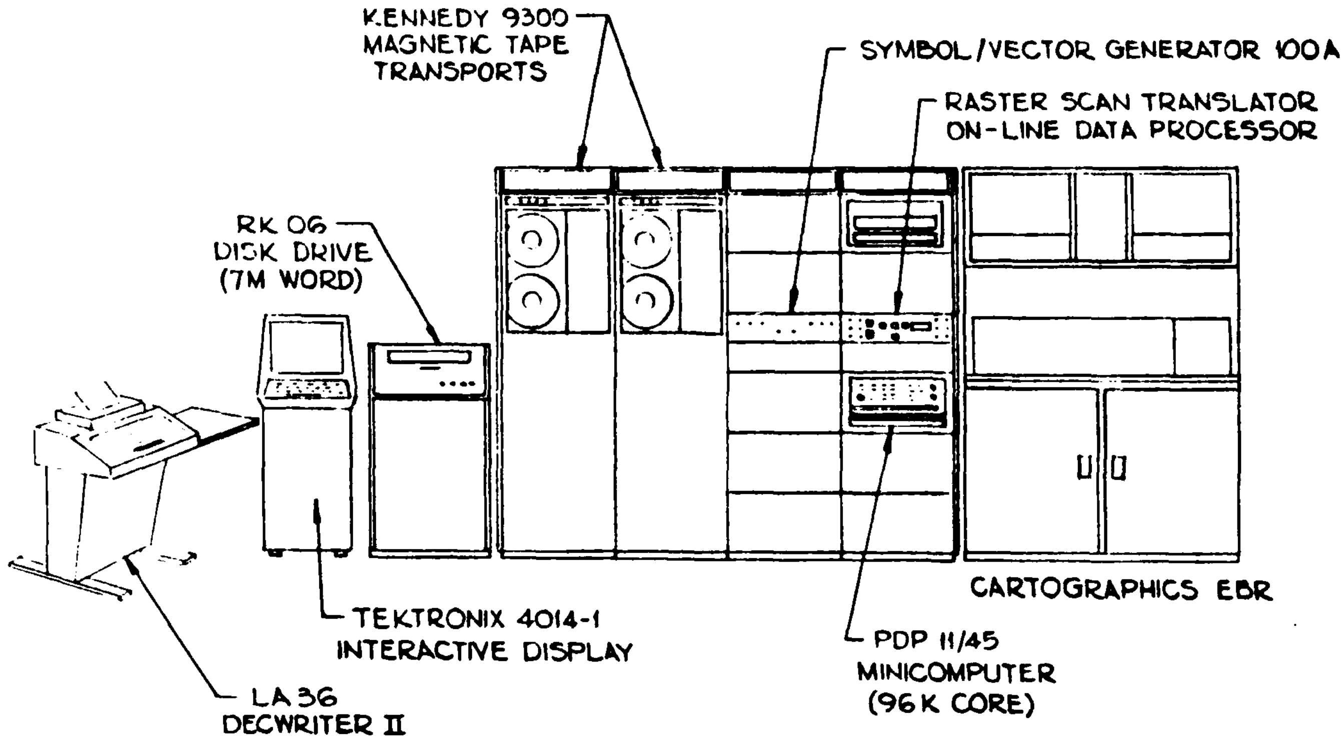

FIGURE 2. Equipment Layout of Cartographics EBR System

Vector

The Vector Mode is used for plotting lines, grids, contours, rivers, streams, roads, stroke characters, etc. Vectors can be generated either incrementally (adjacent points in any one of 8 directions) or as stroke vectors, having a maximum length of 1024 address points.

Line widths are selectable from 6 microns to 261 microns with 6 bit (64 levels) control in 4 micron increments. Greater line widths can be achieved by juxtapositioning line segments.

Figure 3 is a typical example of a contour sheet and a grid overlay recorded with a Cartographic EBR using the Vector mode. Figure 4 is a typical example of an Aviation FLIP Chart recorded in the Vector Mode.

Symbol

The Symbol Mode is used to compose and record graphic arts quality symbols for names sheets, text or symbology using a randomly positioned subraster. Character or symbol sizes can be varied from 8 to 250 mil inches and rotated in 1^{o} increments to follow "serpentine" features of a map or chart.

Recording rates for characters or symbols vary from 20 to 1000 characters per second, depending upon style, size and quality.

Figure 5 is a typical example of graphic arts quality characters recorded with a Cartographic EBR in the Symbol Mode.

Raster

The Raster Mode is used to record raster scan data or sensor imagery using either digital or analog rasters. The digital raster data may be incrementally recorded point by point or run length encoded for data compression and higher throughput rates.

Raster configuration is extremely flexible and may be varied upon computer command from 500 - 32000 elements per scan and from 500 to 32000 lines per raster.

The analog raster generates scan rates which are continuously variable from 10 to 2000 scans per sec. Image recording time is dependent upon scan rate selected, image format, input data, and magnetic tape drive speed i.e. 125 inches/sec.

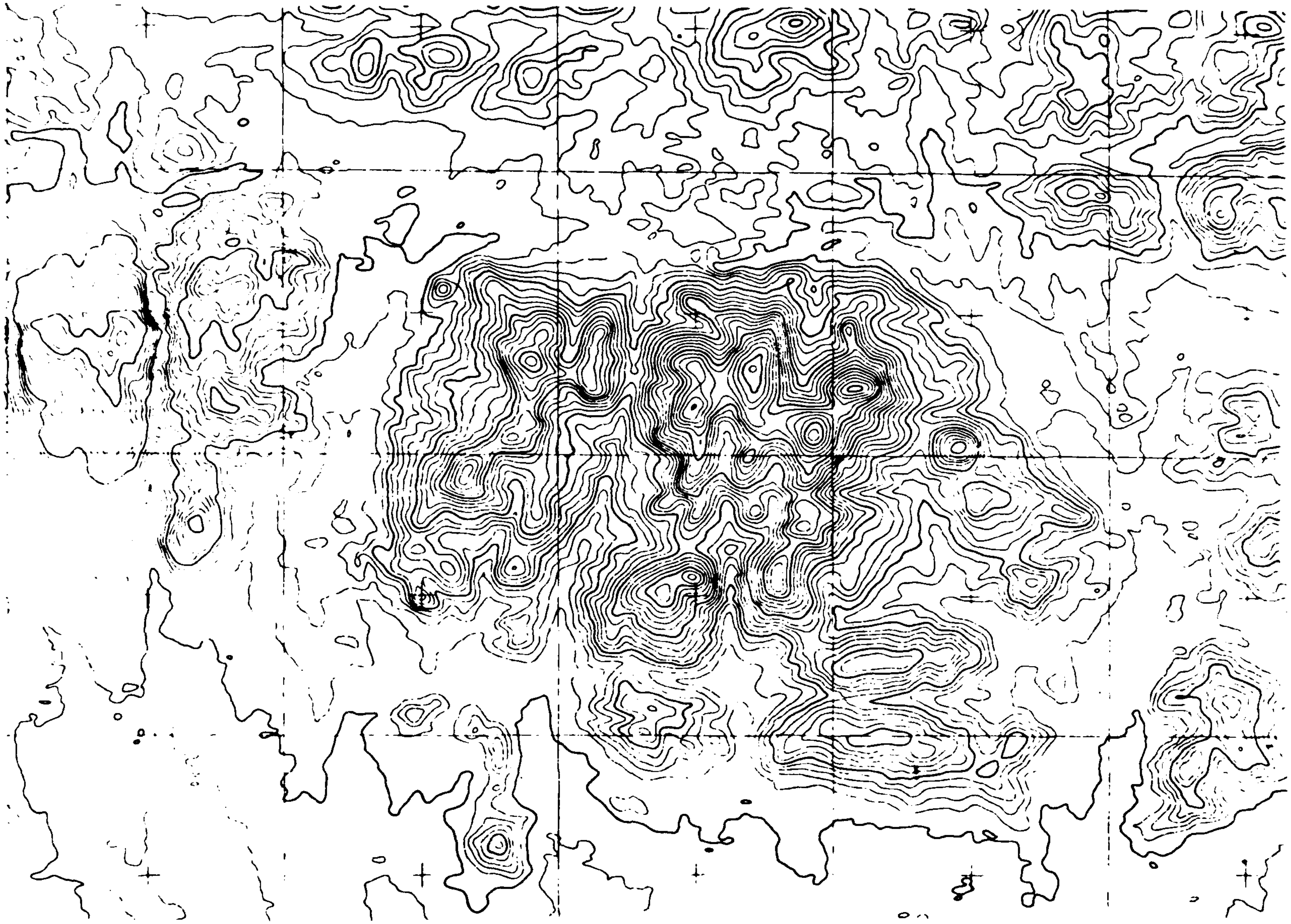

FIGURE 3 Enlargement of Contours & Grids Plotted in Vector Mode

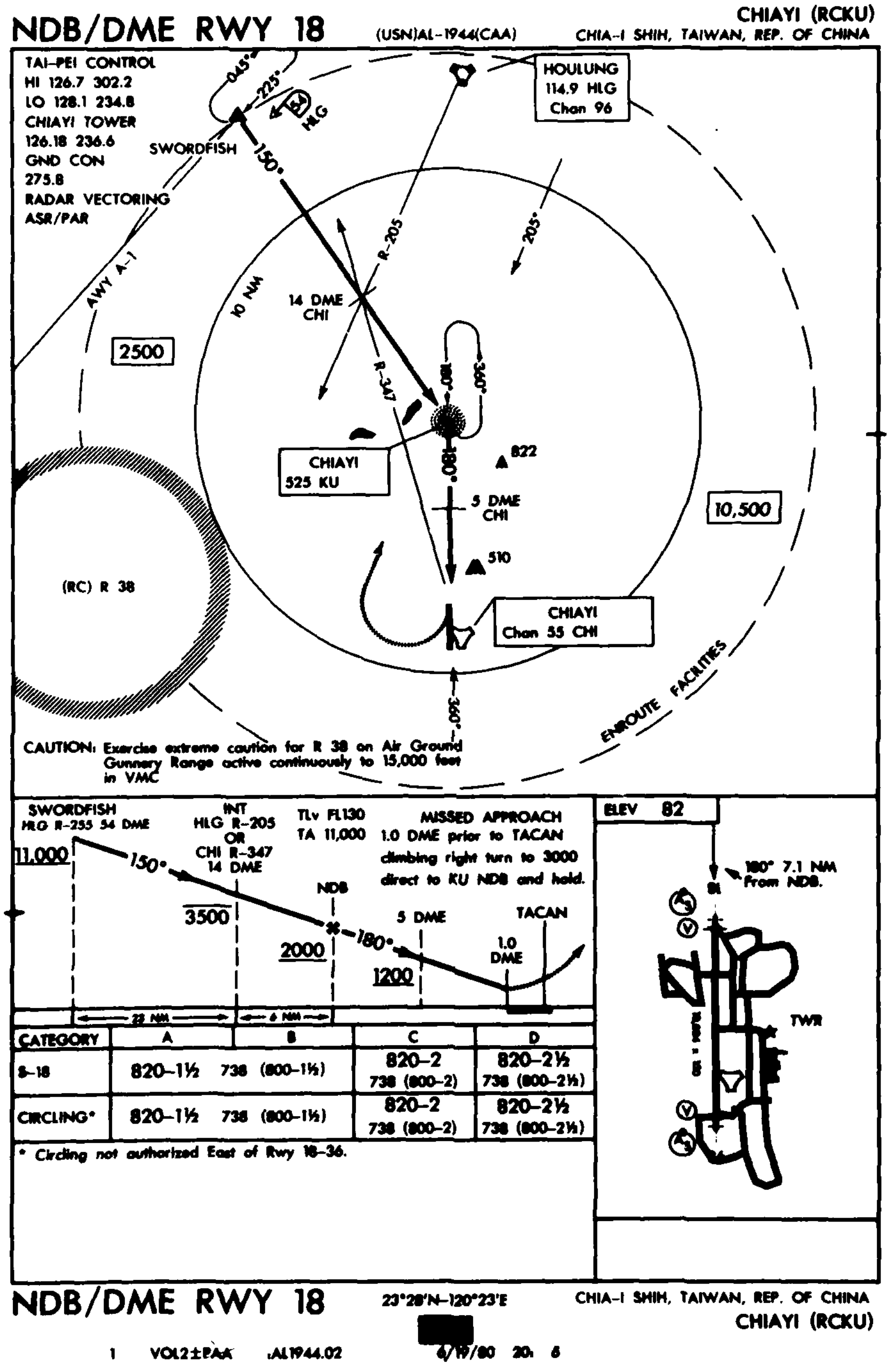

FIGURE 4 Aviation FLIP Chart Recorded in Vector Mode

H	I	J	K	L	M	N
T	U	V	W	X	Y	Z
	a	b	c	d	e	f
l	m	n	o	p	q	r
x	y	z		■	⌖	

FIGURE 5 Enlargement of Graphic Arts Quality Characters Recorded in Symbols Mode

Figures 6 and 7 are examples of high resolution images recorded in the Raster Mode.

Figure 8 is an example of a digitized radar display recorded in the Raster Mode.

In addition, the Raster Scan Translator in the Cartographic EBR has an internal Diagnostic Mode of Operation to record calibration test patterns that can be used to measure resolution, density range, transfer characteristics and geometric fidelity of the EBR.

2.2 System Configuration

The Cartographic EBR System is normally operated as an off-line stand-alone system using digital data from magnetic tape as an input. However, the EBR may also be used on-line with computers or sensors if suitable interfaces are provided.

The basic configuration of the Cartographic EBR System is shown in Figure 9. It consists of six functional sections:

1. Input Section
2. Control Section
3. Mass Data Storage
4. Data Translator
5. Recorder Unit
6. Operating Software Package

2.2.1 Input Section

The Input Section to the Cartographic EBR consists of two 9 track magnetic tape systems, which accept industry standard 1/2" magnetic tape with data densities of 800 or 1600 bpi and operates at 125 ips. a Decwriter II keyboard console and a Tektronix 4014-1 keyboard console. The input system stored as data files control the flow of data to the CPU needed to generate each of the Cartographic products or high resolution imagery. The Decwriter and the Tektronix 4014-1 are used as auxiliary input/output (I/O) communications links with the CPU.

For names or symbol placement, the input commands call out the type of character style or special symbols which are stored on-line on a magnetic disk as digital representations and commands to the CPU to transfer the characters or symbols into computer memory. The input tape also provides recording parameters such as size, angle and position for controlling the Symbol/Vector Generator.

FIGURE 6 - Example of Image Recorded in Raster Model (AERIAL)

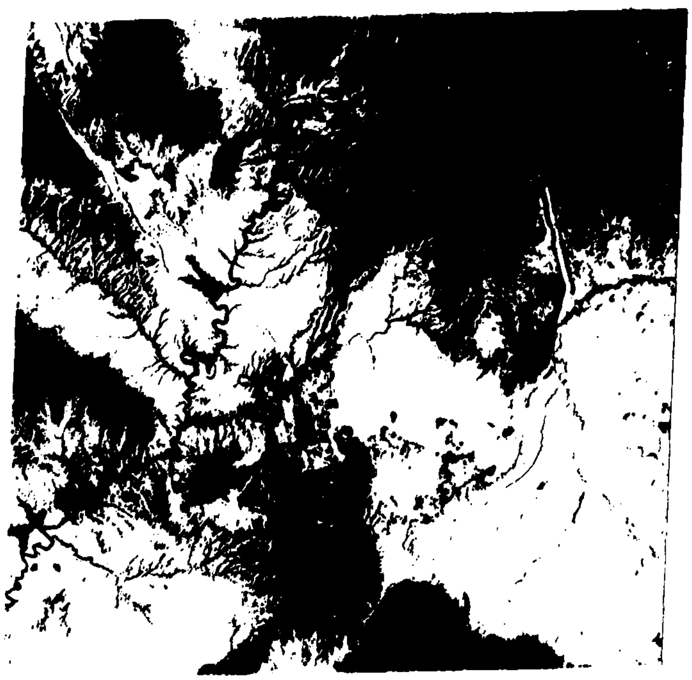

FIGURE 7 Example of Image Recorded in Raster Mode (LANDSAT)

FIGURE 8 - Example of Images Recorded in Raster Mode (RADAR)

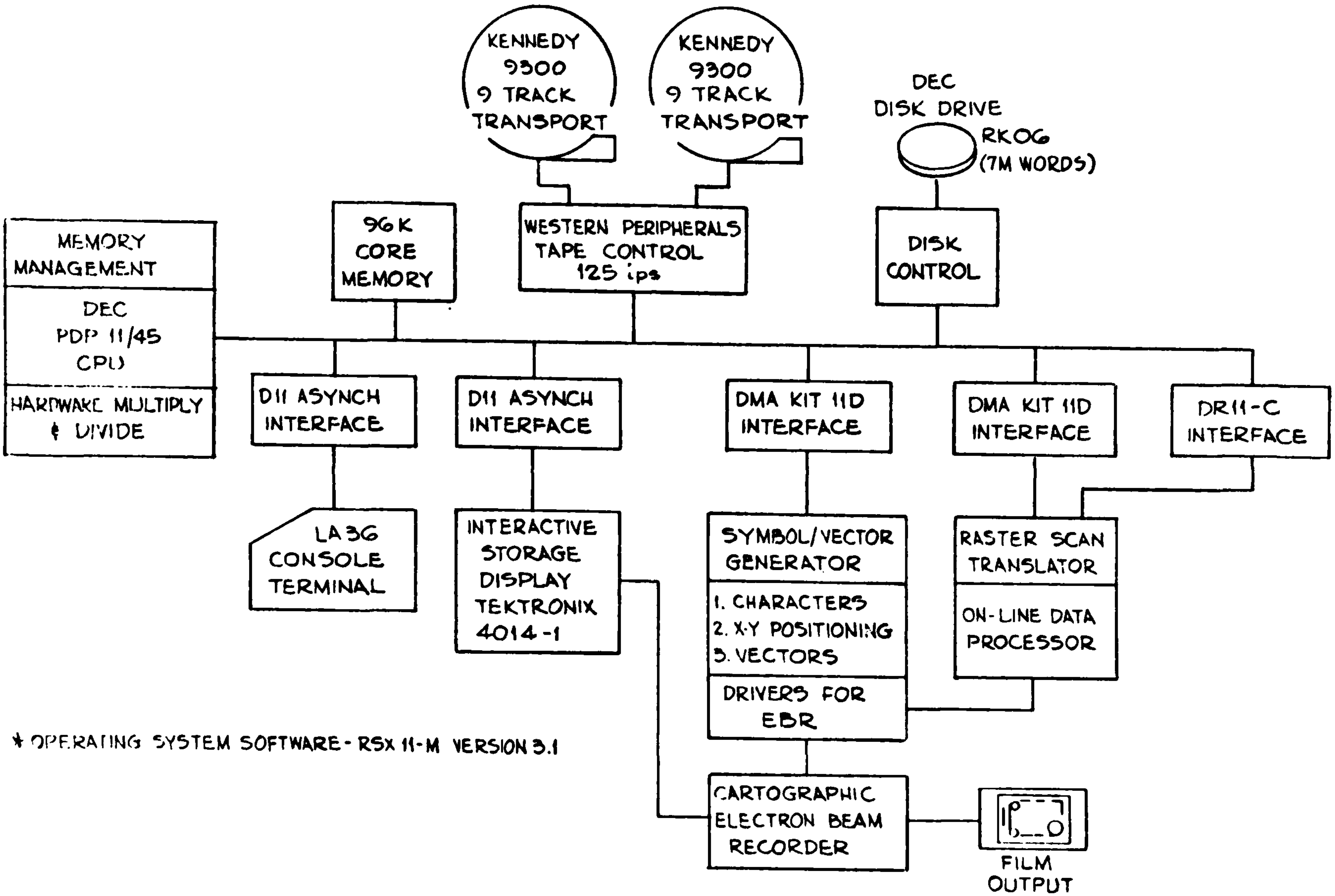

FIGURE 9 Cartographic EBR System Block Diagram

For plotting lines, arcs and contours of variable widths, the input data files supply command codes to the minicomputer and Symbol/Vector Generator for computing position of the electron beam and variations in angle and line width.

For high resolution imagery or raster data, the input data files are supplied as an 8 Bit code to the minicomputer for controlling the Raster Scan Translator. The raster data may be binary or run length encoded for recording either black and white or grey level data.

2.2.2 Control Section

The Control Section consists of a Digital Equipment Corporation (DEC) PDP 11/45 minicomputer which is a basic binary processor with a 16 bit word and 96 K words of memory. The CPU combines operating data and plotting instructions to the data translator to generate and position symbols, vectors, point plots or continuous tone data.

The CPU controls the digital data which is then converted into analog signals which in turn precisely control the electron beam.

2.2.2.1 Computer Controller Architecture

The computer controller used with the Cartographic EBR is shown in Figure 9. The Central Processing Unit (CPU) is a Digital Equipment Corporation (DEC) PDP 11/45 with an RSX 11M Version 3.1, disk operating software system. This hardware/software combination enables maximum flexibility and growth potential, high speed, multifunction operation, future program development and compatibility with existing software being developed by U.S.A.E.T.L., DMA and CIA. All RSX 11M utilities and options, including DECNET 11 network support, can be added without modifying the EBR System.

Direct Memory Access (DMA) channels interface the EBR via the Symbol/Vector Generator (SVG) and the Raster Scan Translator (RST) to the PDP 11. These DMA interfaces have their own drivers and can be treated as standard RSX peripherals such as disk or magnetic tape units.

The Computer Controller for the EBR is assembled in four cabinets consisting of the following:

PDP 11/45 Central Processor Unit

16 Bit Read/Write Core Memory

96KWords Parity Core Memory

Programmer Console

Automatic Power Fail Detection/Restart Capability

4 Level Automatic Interrupt

Line Frequency Clock

Multi Device (Auto Bootstrap Loader)

Extended Instruction Set (Hardware Multiply and Divide)

Memory Management

Current Loop (2-MA) Serial Line Interface

Kit 11 D Direct Memory Access Interface (3)

DL 11 Asynchronous Interface (300 baud line)

DL 11C 16 bit parallel interface

RK611 Disk Drive Control including one RK06, 7M word disk drive, (Separate Cabinet)

Peripheral Mounting Panel

Tape Control with two 9 track, switchable 800/1600 bpi, 125 ips, tape transports.

LA 36-CA Decwriter II Console Terminal

The Tektronix Interactive Storage Display, (Model 4014-1) with Enhanced Graphics Option, which is also provided, may be operated in two modes: (1) via an analog adapter to the EBR, thereby displaying the recording in process at lower resolution and (2) through an asynchronous interface to the CPU.

2.2.3 Mass Data Storage

A DEC 7 million word disk has been provided for storage of operating programs and of digitized representations of type fonts and symbols. The disk can be used as an on-line library for fonts.

Additional disks (up to 8) can be added to the controller to expand storage capacity for additional software programs or Font Libraries.

2.2.4 Data Translator

The Data Translator Circuits of the Cartographic EBR are contained in the Symbol/Vector Generator (SVG), the Raster Scan Translator (RST) with the On-Line Data Processor (OLDP) option. The SVG and the RST, convert digital data into analog signals which drive the EBR and the Tektronix storage display.

2.2.4.1 Symbol/Vector Generator (SVG)

The SVG consists of the following:

Incremental Point Plot Generator

Stroke Vector Generator with Intensity Control

Character Generator

Random Access Positioning Unit

Output signals to the Tektronix Storage Display Controls

The Symbol/Vector Generator, IGI SVG Model 100A, is a single unit which contains the X-Y positioning, character generation and stroke vector generation functions as shown in Figure 10.

The X-Y Positioning Subassembly provides absolute X-Y positioning over the entire EBR format with 32K addressability. The use of a 2^{18} internal addressability ensures that positioning errors levels become insignificant. The X-Y Positioning DAC's provide major beam positioning voltages or start addresses for all character or vector operations and are updated with absolute character right bearing (width) or vector end point coordinates after each operation to insure that errors will not be accumulated.

Line width control from 6 to 261 microns has been provided using either spot wobble or by repeating line segments. Line widths up to 250 mil-inches, may be achieved by repeating line segments.

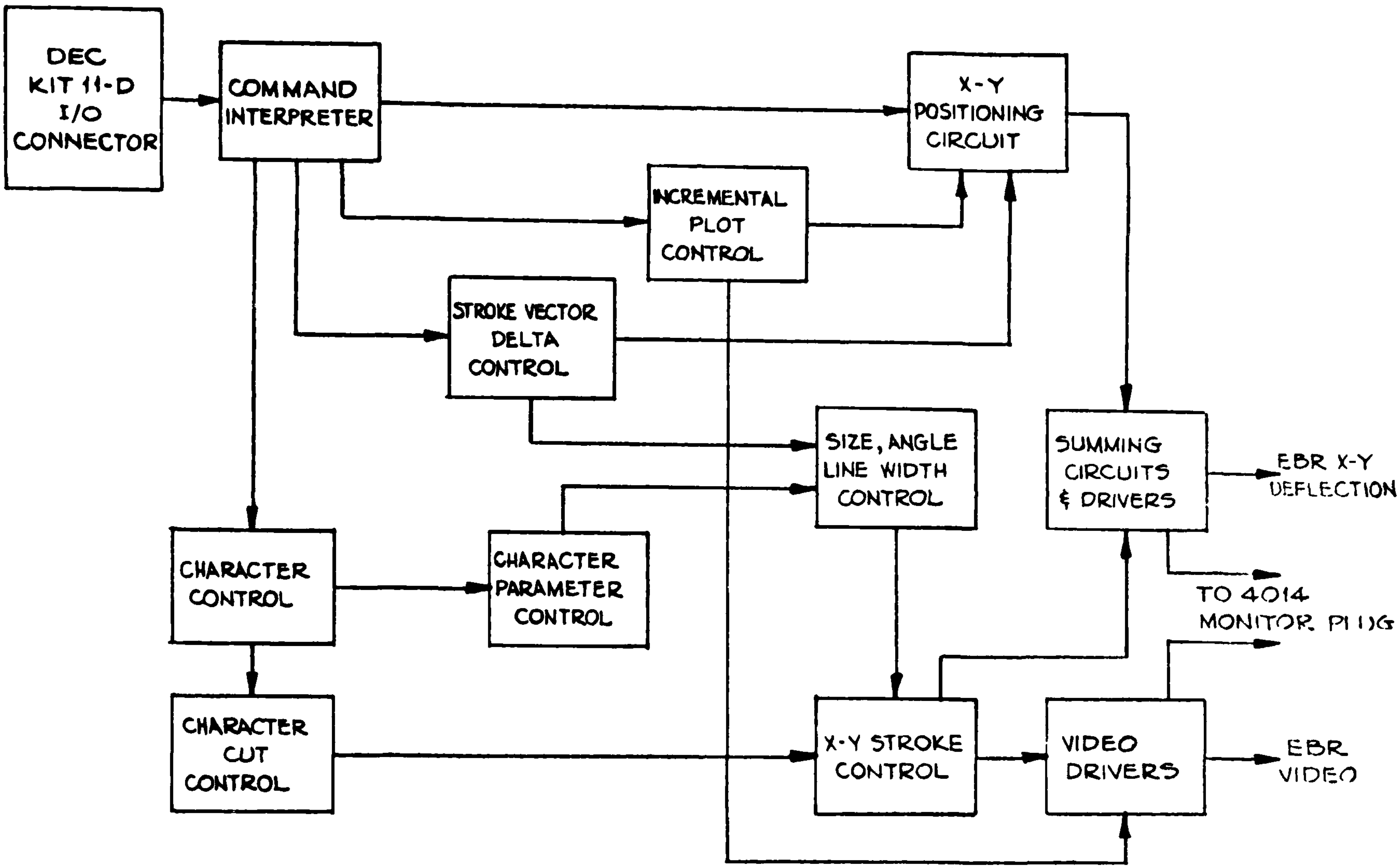

FIGURE 10 Symbol/Vector Generator (SVG) Block Diagram

The Character Generator has the ability to provide Graphic Arts quality characters in sizes of .008" - .256" at EBR scale. Characters are rotatable to a full 360 degrees in 1^{o} increments. The number of allowable cuts per scan line is limited to 108 or 216 depending on whether a low or high resolution font is specified. The area scan writing rates and wobble frequency are kept constant to maintain correct density for different character sizes and line weights. An intensity command in the software has been provided for control of intensity.

The two word end point format for the SVG stroke vector is both efficient and easy to program for long vectors, but is inefficient as the length of the vector stroke decreases, because 70 µSEC is required for calculating and positioning random vectors regardless of length. Since cartographic material contains numerous small vectors such as those found in curves, the SVG also accepts an 8 bit Incremental Vector Plot (IVP) format. Two computer words (16 bits per word) can command the SVG to write one stroke vector or four IVP vectors.

The stroke vector generator generates the base line of symbols produced by the character generator to allow even greater accuracy in character rotation and improved rotation accuracy to less than 1^{o}.

The logic section of the SVG consists of three removable 16" x 7½" wire wrap circuit boards: Board 1 the digital control section; Board 2 a hybrid digital/analog section for character processing and major position deflection and Board 3 a hybrid digital/analog section containing the stroke vector generator, character sub-raster generator and sin/cosine generators. The logic boards are mounted on slides and hinges for easy access for servicing. All connections to boards are through plugs or connectors, thereby, allowing fast replacement. The top and sides of the logic box are removable when the box is withdrawn on slides from the standard cabinet.

Included in the SVG enclosure is a regulated power supply which provides +15V @ 2A, -15V @ 2A and -5V @ 17A. Power input to the SVG is a standard 120V, 60 Hz line cord equipped with a circuit breaker. Signal inputs to the SVG controller are through two 40 pin flat cable connectors on a rear connector panel. Signal outputs of the SVG are through 3 triax and one multi-conductor cable connectors on the rear connector panel.

The SVG Controller interface for the PDP 11/45 mounts in one system unit and requires system power of +5 volts ±5%, 3 Amps. All I/O cables for interfacing to the SVG, unibus connector module (for interface to PDP 11 unibus) are provided with the SVG Controller.

2.2.4.2 Raster Scan Translator

The Raster Scan Translator (RST) hardware and software provided with the Cartographic EBR has 32K byte storage capacity which allows both digital and analog raster imagery and data to be recorded.

Recording data may be organized in one of the following manners:

a. Binary continuous tone grey scale
b. Run length encoded continuous tone grey scale
c. Sequential binary black & white, or
d. Run length encoded black & white.

Data for digital raster mode is organized as either binary (black & white or grey scale) or run length encoded black & white.

Data for the analog raster is recorded a line at a time, as continuous tone grey scale or black & white. Continuously variable scan rates, which cover the range of less than 10 cycles/sec to 2,000 cycles/sec (100 msec. to 0.5 msec. per line) have been provided for the analog raster.

The CPU controls the digital data which is then converted to analog signals which control the precision electron beam over the film format. Corrective signals for linearity, geometry and astigmatism may be introduced at this time.

A video processor which includes a Gamma Amplifier is supplied for the Raster Operating Mode. The Gamma Amplifier may be used for enhancement of continuous tone imagery by varying the gamma transfer characteristic of the video signal from 1/2 to 2.

2.2.4.3 Format and Size Controls

An Automatic Format and Size Control has been provided which automatically sets the image size, aspect ratio and other recording parameters when an operator presses a single pushbutton on the Cartographic EBR operation control panel. The controller is interlocked with various interchangeable film transport mechanisms, thereby preventing possible operator errors when changing from one recording mode to another.

An automatic offset control is provided to select the position of the image origin (X = 0, Y = 0) in the recording address matrix for each recording format.

2.2.4.4 On-Line-Data-Processor (OLDP)

The On-Line-Data-Processor consists of supplementary hardware circuitry installed in the Raster Scan Translator of the Cartographic EBR System which allows correction and control of geometric and radiometric image data errors. Typical correction or controls that may be introduced during recording are:

Spot Size (Line Width)
Exposure (Image Contrast and Density)
Skew
Horizontal Offset
Horizontal Rate
Vertical Offset
Video Transfer Characteristic
 (Linear or gamma corrected)
Video Polarity

The OLDP enables the Cartographic EBR to translate computer controlled digital commands into adjustments of spot size, exposure, scan rate, geometry or video.

A similiar approach is used in the framing EBR used for recording Earth Resources Technology Satellite (ERTS) imagery in Brazil and is directly applicable to other EBR imaging systems.[11] The On-Line-Data-Processor has the characteristics shown in Table 1.

TABLE 1 - COMPUTER CONTROLLED CORRECTIONS DURING RECORDING

CORRECTION OR CONTROL	RANGE	DISCRETE LEVELS
Exposure (coarse)	RBS or MSS Total Range +20% 0% +40% -20%	2
Exposure (fine)	$\pm$ 20%	64
Vertical Offset (coarse)	$\pm$ 6.25% $\times \frac{8}{FS*}$	4,096
Vertical Offset (fine)	$\pm$ 1.25% $\times \frac{8}{FS*}$	4,096
Horizontal Offset	$\pm$ 6.25% $\times \frac{8}{FS*}$	4,096
Horizontal Rate	$\pm$ 40%	4,096
Skew	$\pm$ 10% ($\pm \tan^{-1} .1$)	4,096
Spot Wobble	40:1	256
Video Polarity	positive or negative	2
Video Transfer	manually adjustable gamma correction, software selectable (in or our)	

*FS = Format Size in Inches

2.2.5 Recorder Unit

2.2.5.1 General

The Recorder Unit of the Cartographic EBR System is a large format Electron Beam Recorder (EBR). The EBR is an instrument which converts electrical signals representative of map features, alphanumeric characters, graphic plots, seismic information or variable density pictures into latent images on electron sensitive film. The latent image is formed by exposing the film with a precisely controlled, finely focused electron beam. The EBR may be regarded as analogous to a cathode ray tube (CRT) recorder where the lens and the phosphor faceplate have been removed and the recording medium placed in the vacuum.

The EBR, shown in Figures 11 and 12 is uniquely suited for applications which require high resolution, fast recording speed and wide dynamic range.

The EBR consists of the following major items: (a) cabinet, (b) vacuum system, (c) electron optics, (d) film transport and (e) electronics.

The EBR, as shown schematically in Figure 13, features a high resolution electron gun; an electromagnetic system for focusing, deflecting and controlling the electron beam; film transport mechanisms for handling various film media; a fully automatic vacuum system which maintains suitable vacuum in various parts of the recorder; and a number of highly regulated power supplies, electronic circuits and monitors.

2.2.5.2 Vacuum System

The vacuum system of the EBR is a fully automatic, three stage, differentially pumped system, designed for continuous operation with failsafe protection in the event of accidental power loss. Interlocks are provided to prevent the switching on of the high voltage supply, the electron gun filament supply, or the start of recording prior to the attainment of operational vacuum.

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FIGURE 11 CARTOGRAPHIC EBR

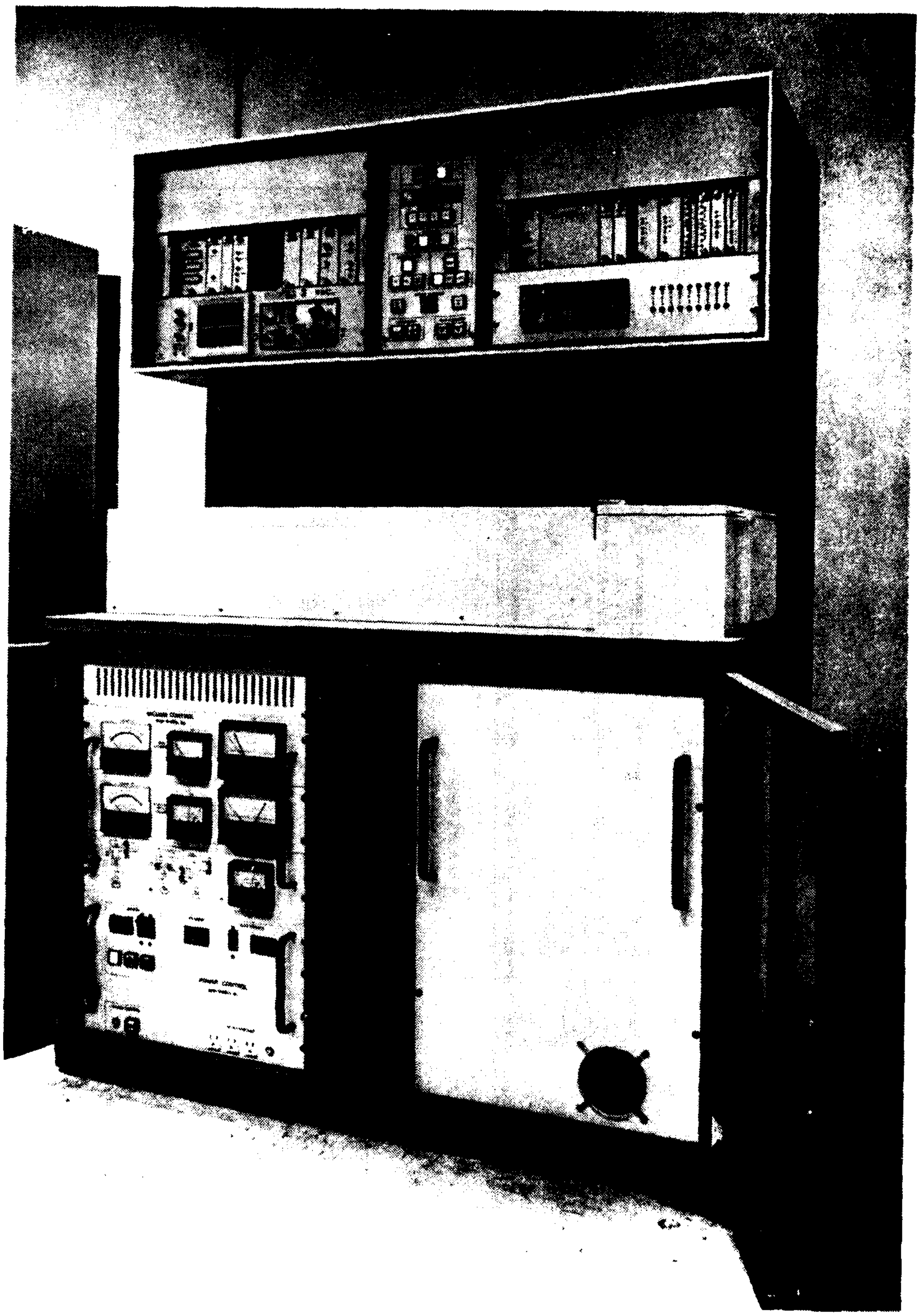

FIGURE 12 - EBR WITH FRONT DOORS OPEN AND PANELS REMOVED

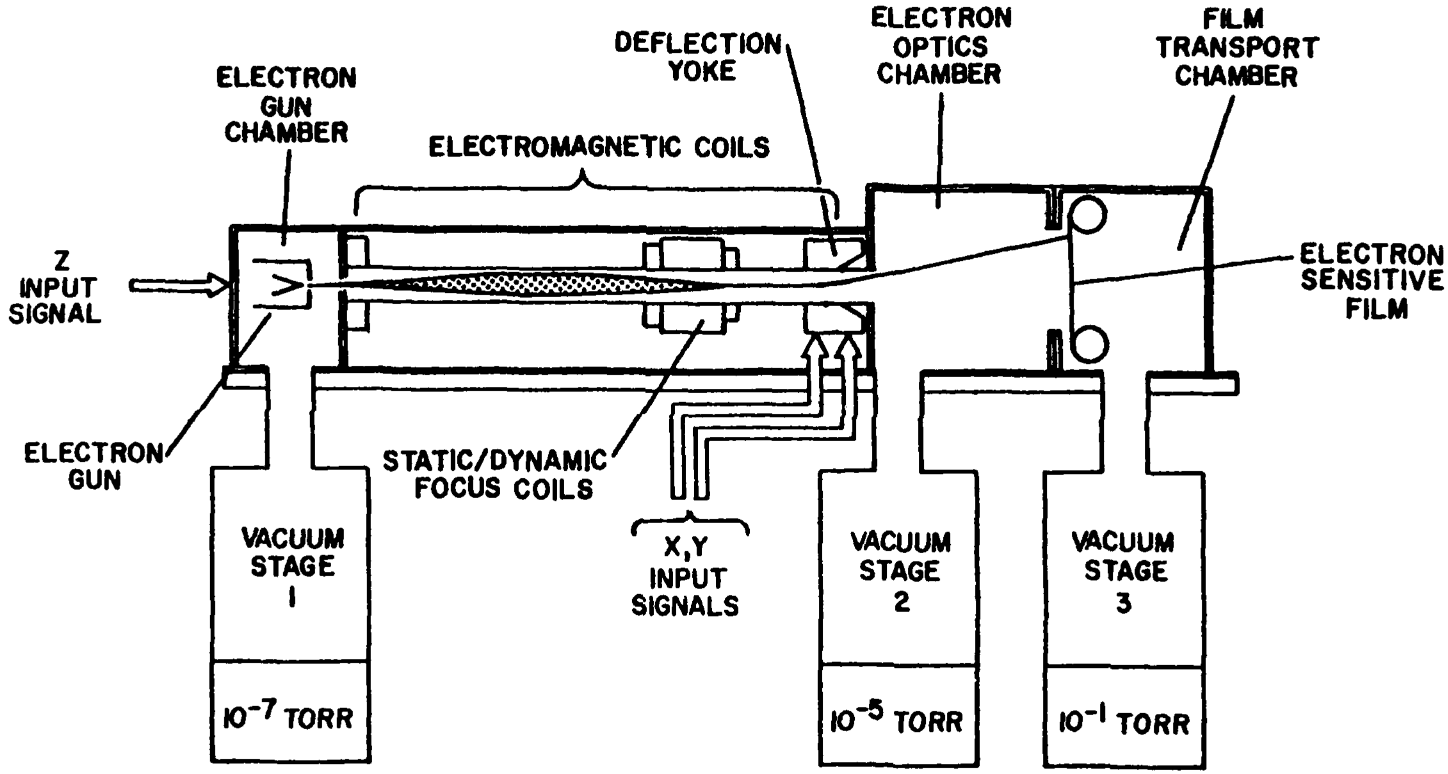

Figure 13 Schematic Layout of Cartographic EBR

This high performance vacuum system insures thousands of hours of electron gun cathode life, rapid achievement of operational vacuum from a completely off status and less than 5 minute pump down of a fresh load of film. The vacuum system capacity handles outgassing of film at approximately one square inch per second of the format film area, thus a 5 X 8 format can be exposed every 40 seconds, a microfiche format every 24 seconds, and a 70mm format every 4 seconds.

Operation of the vacuum system is controlled by two push buttons on the EBR Control Panel. As operational vacuum is achieved in the three principle sections of the EBR, vacuum status is displayed on the EBR operation control panel by indicator lamps. Since the vacuum system is fully automatic, interlocked and fail-safe, no prior vacuum technical background or experience is required to operate the EBR. The operator is merely required to load film.

2.2.5.3 Electro-Optics

The electro-optics components of the Cartographic EBR consist of an electron gun which produces a beam of electrons from a thermionic emitter cathode; an alignment yoke for positioning the beam through the center of a high resolution static and dynamic focus coil which focuses the beam of electrons into a concentrated round spot approximately 6 microns in diameter; an astigmatism corrector for removing residual spot distortion caused by any magnetic asymmetry in the focus coil; a high performance deflection yoke which is capable of positioning the electron spot across the format without introducing any appreciable spot distortion or spot growth; a spot wobble yoke which is used to provide automatic line width enlargement; and magnetic shields to prevent interference of magnetic fields with the electron beam.

2.2.5.4 Film Transports

Since the Cartographic EBR System will be used as a preproduction model at the DMA Centers for the automated production of maps and other micrographic products, the EBR is specifically designed to accept a variety of film transport mechanisms. All film transports are easily interchangeable and precisely located by a dowel pin in the Film Chamber.

Two film transports are provided with the Cartographic EBR: a 5½ inch non-perforated film transport, and a 70 mm perforated film transport with precision registration pins. Optional film transports available from IGI for the Cartographic EBR are: 5 inch and 105 mm (non-perforated film) and 35 mm (perforated film).

5½ Inch Film Transport

The 5½ inch film transport, which is installed in the Cartographic EBR is of unique and proprietary design and is shown in Figure 14. It has a recording aperture of 8-9/32 x 5-1/32 inches which is adequate for recording standard "Flip Charts" at full scale. This transport features a curved film gate and constant film tension which ensure a consistent and repeatable positioning of the recording film. Advance, for the non-perforated film is metered to a constant length of 10 inches.

The film transport is provided with an automated registration hole punching mechanism to ensure the accurate superimposition of recorded images. The distance between the two registration holes along the center line of a film frame is exactly 9 inches and the diameter of the registration holes is 0.2500 ± .0002 inch.

The film transport is designed to accept film wound on large diameter (either 2 or 3 inch) cores instead of small diameter spools, thus eliminating "core-set" problems.

All materials used in the fabrication of the film transport are vacuum compatible and non-magnetic. The film gate is hard chrome plated and highly polished to ensure that the normal operation of the film transport will not cause any film scratching.

Operation of the frame advance mechanism is controlled either manually from the control panel or automatically, as the recording of an EBR image is completed.

70 mm Film Transport

The 70 mm film transport provided with the Cartographic EBR is shown in Figure 15. It incorporates a C-70-14MS (Hollywood Film Co.) pin registered film movement which has a 14 perforations (i.e. 2·618 inch) pulldown. The recording aperture of the 70 mm film transport is 2·6 x 2·3 inches. When installed in the EBR, the location of the 70 mm film plane corresponds exactly to that of the 5½ inch film transport;

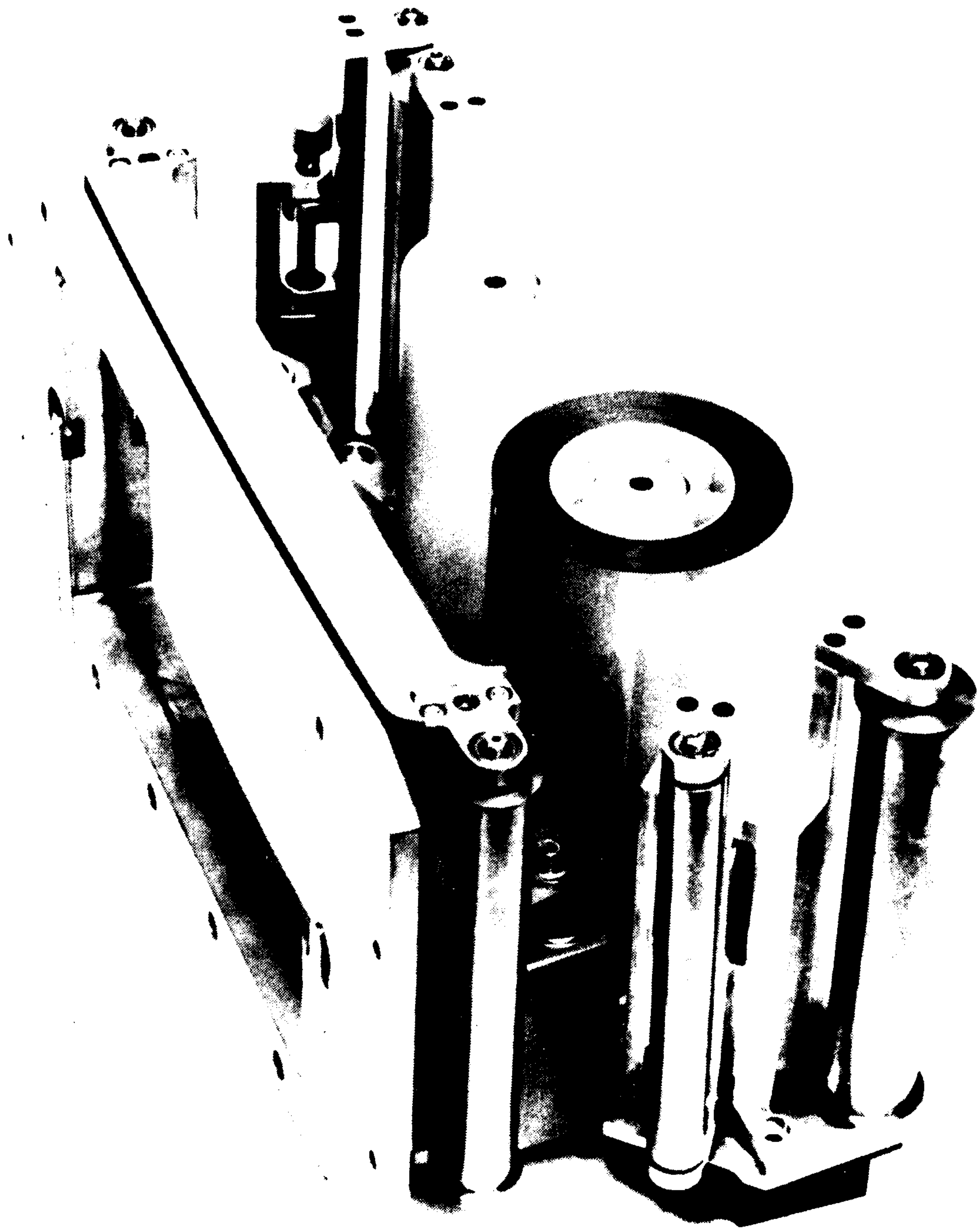

FIGURE 14 5½ Inch Film Transport

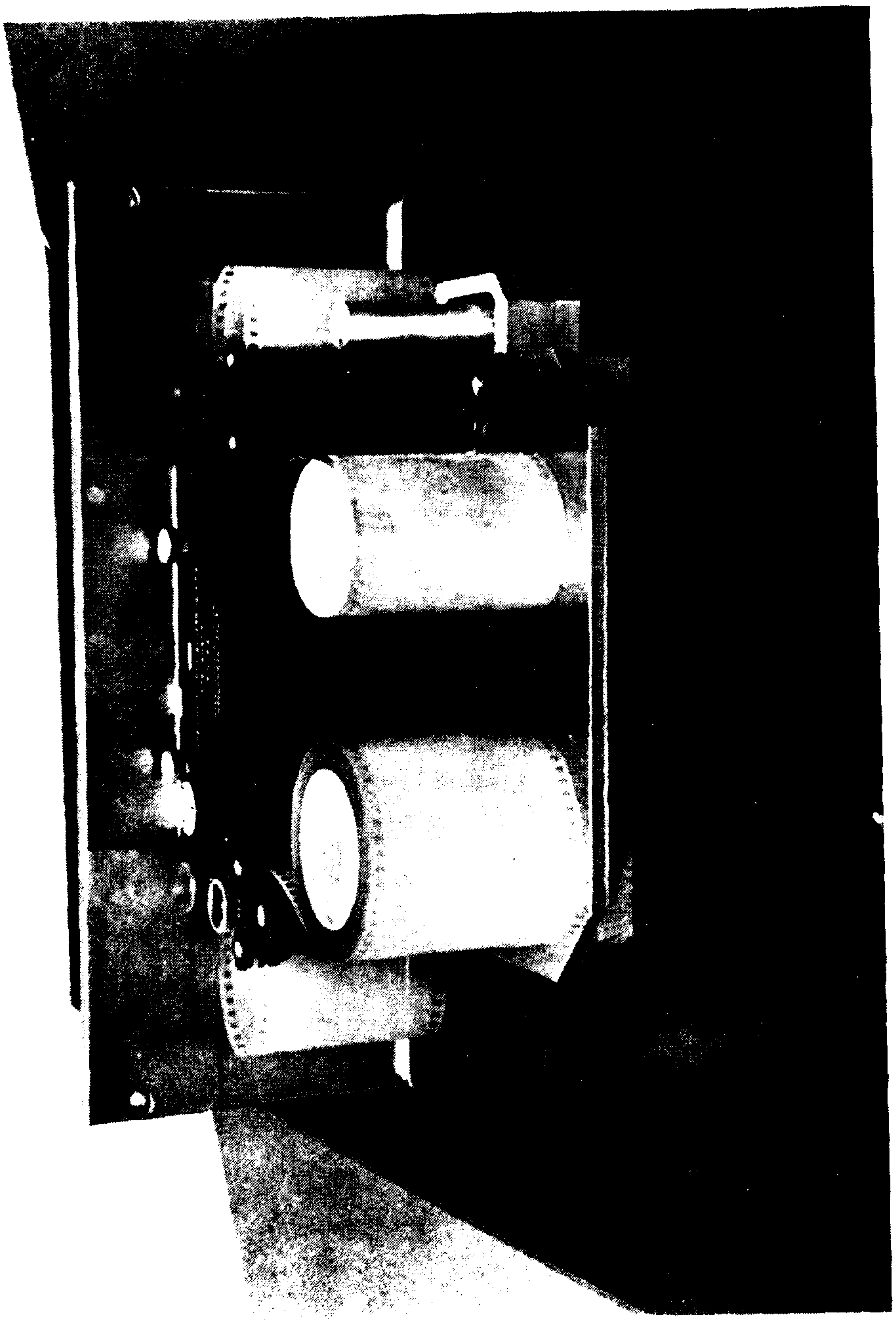

FIGURE 15 - 70 mm FILM TRANSPORT

consequently, there is no need to refocus the electron beam when film transports are interchanged.

2.2.6 Operating Software Packages

The Operating Software Package, provided with the Cartographic EBR System, controls the interaction and operation of the input section, the CPU, the data generators and the recording unit. It consists of:

a. DEC RSX 11M Operating System, Version 3.1

b. IGI System Utilities Programs - VSP, FLU and RAS

The EBR System utilities that are provided with the Cartographic EBR System are:

a. The Font Library Update (FLU) utility task to create, modify, delete and maintain a symbol library for the EBR.

b. The Vector Symbol Plot (VSP) task which will process magnetic tapes written in the SVG format.

c. Raster Application System (RAS) programs for both analog and digital raster including binary, continuous tone and run length coding.

The VSP task supports all SVG modes of operation resulting in optimum system performance. VSP's standard features include:

1) interactive mode allowing direct operator input via simple alphanumeric input commands.

2) de-bug mode for running error diagnostic and maintenance files stored on disk;

3) tape search, verification and dump facilities;

4) ability to call a user written Fortran subroutine which can be used to translate foreign input tapes to the SVG format.

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2.3 Typical Cartographic EBR System Performance Characteristics

Table II lists some of the typical performance Characteristics achieved by the Cartographic EBR System.

2.3.1 Recording Spot Size and Resolution

The effective diameter of the focused electron spot in the Cartographic EBR is 6 microns. Losses in resolution due to scattering of electrons within the emulsion layer are not significant if proper recording films, such as Kodak SO-219, are used. However, when coarser grain, lower resolution films are exposed in the Cartographic EBR the loss of resolution becomes clearly evident.

2.3.2 Beam Addressability

The positioning of the electron beam in the Cartographic EBR is controlled by 18 bit DAC's so that maximum addressability of 262,144 x 262,144 points per frame is theoretically available, however, currently the maximum addressability has been set to 32,768 x 32,768 points.

The Cartographic EBR is provided with size selector switches which control the size of the address matrix elements. The matrix elements are always square (i.e. of equal size in the X and Y axes) in the 5 selectable recording formats. Thus the addressability per image recorded in the Cartographic EBR depends on the selected size of the image and the selected size of the address matrix element. For example, an 8 x 5 inch image with 1/4 MIL elements has an addressability of 32,000 x 20,000 positions. It should be notes that, should the need arise, the size of the address matrix elements may easily be preset to other values.

2.3.3 Dynamic Range/Density

The Cartographic EBR System is capable of recording images with a D_{max} greater than 2.3 and a D_{min} less than 0.1. As shown in Figure 16, a maximum density in excess of 3.0 and a "fog'plus'base" density of 0.08 can easily be achieved using Kodak SO-219 film.

TABLE II - TYPICAL CARTOGRAPHIC EBR SYSTEM PERFORMANCE CHARACTERISTICS

Recording Formats	208 x 127 mm 162 x 101 mm 66 x 87 mm 64 x 57 mm 43 x 25 mm
Minimum Line Width	6 µm
* Maximum Vector Length	1024 elements (250 mil-inches)
* Line Widths	6 to 261 µm with 6 bit control, in 4 um increments
* Character Sizes	8-256 mil-inches
Character Rotation	1^{o} Increments or Tan^{-1} .001
Addressable Positions	32,768 LSB's for maximum format dimension, other dimension is proportionally lower
Beam Positioning Repeatability	± .003% of maximum format dimension
Geometric Fidelity	± .05% (without software correction)
Maximum Optical Density	2.35+
Density Range	64 Levels for graphics 256 Levels for imagery
Background Density	0.1 density units
Video Bandwidth	DC - 10 MHz
Lineal Data Recording	
Random Points	40,000 points/sec.
Adjacent Points (IVP)	125,000 points/sec.
Stroke Vectors	1,500 - 3,000 vectors/sec depending upon length
Character/Symbol Recording	20-1000 Characters/sec. depending upon style, size and quality
Raster Data Recording	
Elements/Scan	up to 32,768 computer selectable
Lines/Raster	up to 32,768 computer selectable
Scan Rates	10 - 2000 lines/sec continuously variable (64,000 increments)

*Proportionally smaller with format size

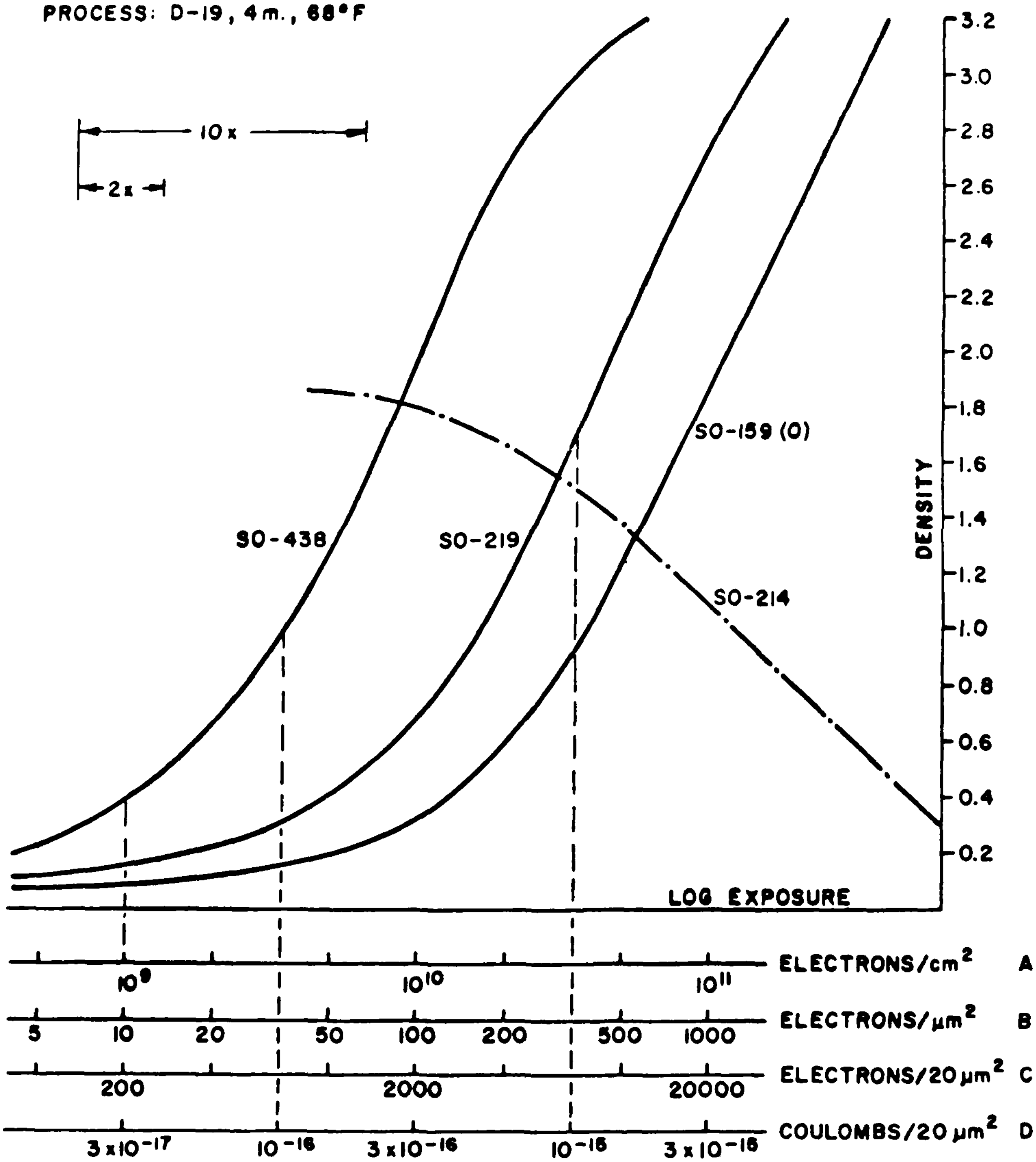

FIGURE 16 Sensitometric Characteristics of Electron Sensitive Films

The signal-to-noise ratio of the video amplifiers in the Cartographic EBR is greater than 100:1, thus with a proper 8 bit input video signal, it is possible to record gray scales with more than 64 distinguishable shades of gray.

Density variations in images recorded in the Cartographic EBR are primarily due to non-uniform or non-repeatable film processing and non-uniformities in the sensitivity of the recording film. It has been demonstrated (for example, on the LANDSAT EBR at GSFC) that with proper film processing and using a very uniform recording film, density variations in electron beam recorded images can be held to about .02 optical density units. However, it should be emphasized that for recording line work, characters, symbols, etc. density variations of 0.2 or even greater can readily be tolerated.

2.3.4 Video Bandwidth

The Cartographic EBR has a bandwidth of 0 to 10 MHz.

In the Vector Mode of Operation (IVP), the Cartographic EBR records at 125,000 points per second, or 8 microseconds per point. Even though the time of exposure per point is limited to about 1 microsecond, to allow settling time for the DACs and the deflection amplifiers, the video bandwidth equivalent to these comparatively short exposure pulses is still well under 10 MHz.

2.3.5 Positional Repeatability

The positional repeatability of images recorded in the Cartographic EBR is affected by many factors, of these the most significant are: a) the stability of the EBR deflection system, b) the dimensional stability of the recording film and c) the repeatability of film positioning in the gate of the film transport. Electrical measurements made using a high performance DVM on the entire deflection system of the Cartographic EBR's and sample recordings made on film, show a short term stability (hours) of better than a .003% and a long term stability (days) of better than .01%. Variations in temperature, humidity, film tension, film conditioning time and film processing can introduce positional image changes of 0.02%, or more.

2.3.6 Geometric Fidelity

The geometric fidelity of images recorded in the Cartographic EBR is controlled by the Geometric Corrections Generator which provides stable corrections for all first, second and third order distortions and partial corrections for fourth order distortions.

The Geometric Corrections Generator is provided with precise adjustments for the following:

Skew
X Bow
Y Bow
Y Diff. linearity
X Diff. linearity
X trapezoid
Y trapezoid
X pincushion
Y pincushion
X radial linearity
Y radial linearity
X edge rotation
Y edge rotation

The accuracy with which the Geometric Corrections Generator can be adjusted is 0.05% of maximum image format. Even better geometric fidelity can be achieved by means of software corrections.

2.4 Recording Film & Film Processing

The Cartographic EBR System uses Kodak Direct Electron Recording Film, Type SO-219 which possesses the following features:

Very high resolution, in excess of 500 LP/mm

Extremely fine graininess, which allows subsequent enlargements of recorded images at magnifications of 50X or more.

High maximum density and gamma which make it particularly suitable for cartographic recording.

An electrically conducting layer under the emulsion, to prevent charging effects.

A very low sensitivity to light, which allows the film to be handled in bright yellow safe lights.

A polyester base which is vacuum compatible and provides excellent dimensional stability.

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The sensitometric characteristic of the Recording Film (SO-219) processed in D.19 chemistry is shown in Figure 11. SO-219 can readily be processed as positive or negative imagery in conventional or high speed automatic film processors.

2.5 Dimensional Stability of Film

Absolute dimensional stability of photographic films does not exist; even photographic glass plates show very small size changes under some conditions. In the photographic industry the all-inclusive term "dimensional stability" is regarded as applying to size changes caused by (1) temperature, (2) humidity (3) processing and (4) aging. Film size changes can be considered as either reversible or irreversible, depending on the cause. Changes due to humidity and temperature are considered reversible, although humidity changes are usually hysteretic. Changes caused by processing and aging are generally considered irreversible, although some processing changes may be at least partially reversible.

Specific data on the dimensional stability of SO 219 film used in the Cartographic EBR is not available from the manufacturer (Eastman Kodak Co.), however, such data can be derived with reasonable accuracy from the detailed information which is available for similar photographic films (see references 12 through 15).

The dimensional stability characteristics of SO 219 film can be summarized as follows:

Thermal Coefficient of Linear Expansion per ^{o}C	.002%
Humidity Coefficient of Linear Expansion per 1% R.H.	.002%
Processing Dimensional Change	$\pm$.03%
Aging: 1 wk. @ 50^{o}C & 20% R.H.	.03%
1 yr. @ 25^{o}C & 60% R.H.	.03%

Understanding the behavior of photographic films in vacuum is important for users of EBRs. On exposure to a moderate vacuum a film strip will lose about 15% equivalent relative humidity in about 10 seconds. The same strip will take about 1 minute to change to the same extent when exposed to air at 5% R.H. The rapid loss of moisture under sudden exposure to vacuum is attended by a cooling of roughly 5°C. The speed at which a strip of film is conditioned in vacuum depends on the degree of vacuum attained. For example, the rate of conditioning at 10^{-3} torr is about 5 times that at 1 torr and 30 to 50 times that at normal atmospheric pressure. A roll of film, on the other hand, appears to condition at approximately the same rate at 1 torr or 10^{-3} torr.

The dimensional stability characteristics of the recording film used in the Cartographic EBR could be improved by increasing the thickness of the base, decreasing the thickness of the emulsion or using a highly stabilized gel emulsion. However, for critical applications which require maximum film stability it is much more important to provide very precise controls on temperature, humidity and conditioning time at all stages of film handling, i.e. in storage, during exposure in the EBR, in processing, in subsequent storage, in viewing or enlarging......etc.

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3.0 Conclusions and Recommendations

1. The Cartographic EBR System may be used for a variety of cartographic, graphics and high resolution image recording applications. Some of the potential applications for the Cartographic EBR installed at DMA HTC are:

Topographic, Hydrographic and Aerospace Maps and Charts

Aerial and Satellite Imagery

Type and Test Composition for Publications

Computer Output Microfilm (COM)

Computer Graphics

Merging Lineal and Raster Data

Photomaps

Graphic Microforms

Proof Plots for CRT Print Head System

Proof Plots for Raster Finishing Plotting System (RAPS)

Proof Plots for Names Placement System (Computervision Data Films)

Proof Plots for Gerber, Concord or Calcomp Plotters

Strip Maps

Automated Air Information Production System (AAIPS) Products

Microfiche Notice to Mariners

Mosaicking of Satellite and Aerial Imagery

Binary, Run Length Code and Facsimile Raster Data

Halftones

Presentation Charts and Data

Microfilm or Microfiche Map Storage System

Tactical Mission Planning Material

2. A multi-up microform capability should be installed in the Cartographic EBR to enable the system to record 16, 32, 64, 128 and 256 pages or images over the recording format. This feature may be used for multiple page layout which can then be enlarged to produce a conventional press plate. Figure 17 is an example of 16 AAIPS FLIP charts recorded at 4x reduction. The multiple-up feature could also be used for storage of charts, or graphics or data on microfiche formats.

3. The preproduction model Cartographic EBR should be eventually upgraded to increase its acceleration potential to 20KV to allow both normal and reversal processing of master recordings.

4. A high quality enlarger platemaker which is capable of producing press plates directly from EBR master recordings should be developed.

5. An additional magnetic disk drive (RK07) should be added to the computer controller to give the system additional storage capacity and capability and redundency of equipment for reliability.

6. The capability of the Cartographic EBR System may be expanded by the addition of other interchangeable film transports such as 105 mm (Fiche) or 35 mm.

7. A high speed character generating mode should be added to the Cartographic EBR for recording conventional microfiche data.

8. The use of a special text recording mode in the Cartographic EBR System for producing various books and manuals should be investigated. The present symbol/character generators in the Symbol/Vector Generator and the associated software are designed primarily for charts and maps where random positioning, scaling and rotation of characters are important. This technique necessitates the use of extensive software overhead which reduces the character and symbol rate. In typesetting for books and manuals, character placement, size and orientation are predictable and therefore could be accomplished with a much lower software overhead and consequently recorded at a much high speed.

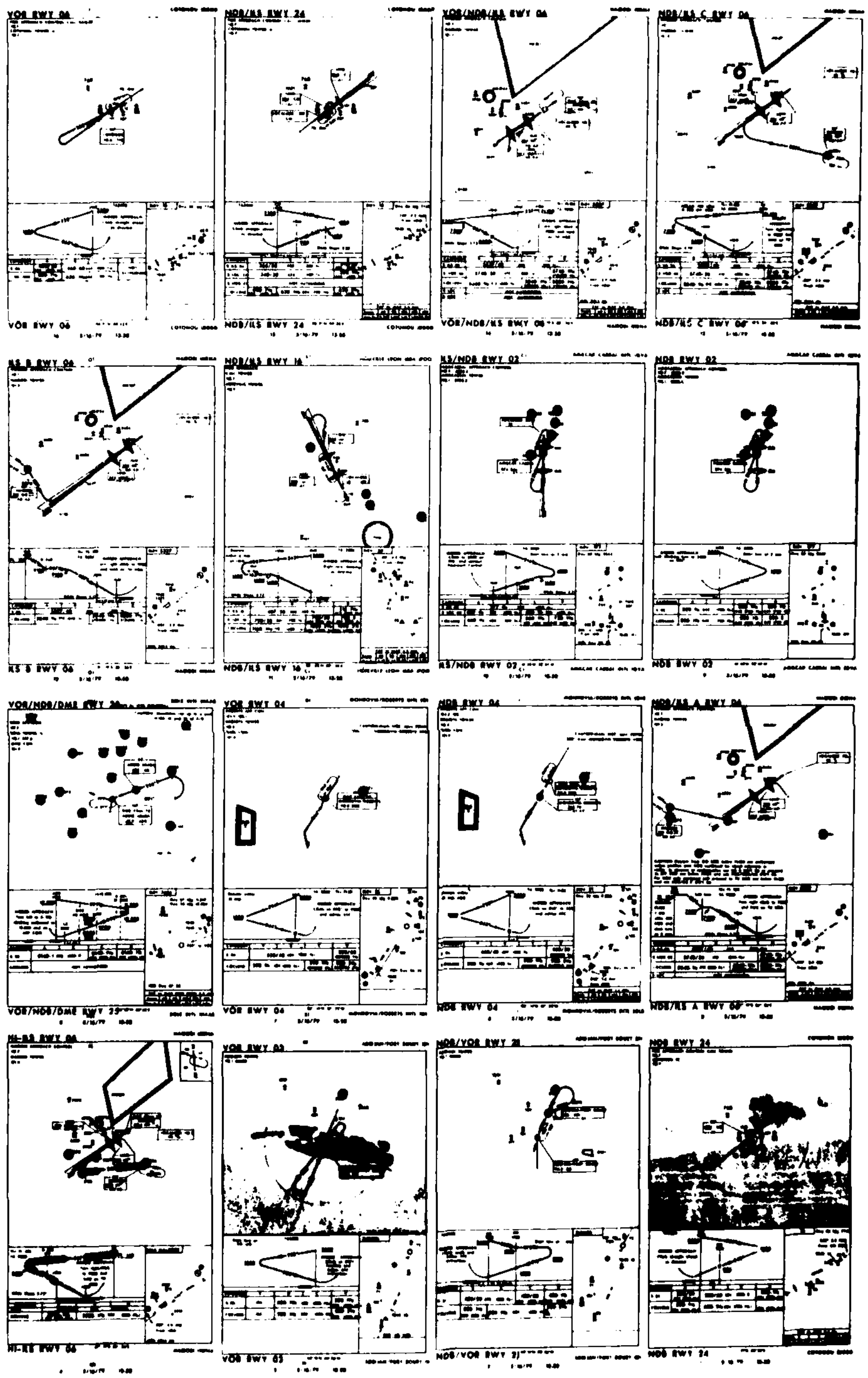

FIGURE 17 Example of Multi up Microform - Containing 16 AAIPS FLIP Charts

9. Recent advances in digital to analog converters indicate that a higher accuracy Symbol/Vector Generator could be developed which would further enhance the Cartographic EBR capability. It is recommended that the analog computation section for vector angles of the SVG be replaced with a more precise digital calculator.

10. Recent advances in EBR design and construction have eliminated some small image defects caused by the interaction of the deflection yoke and the metal vacuum chamber. These new design improvements should eventually be incorporated in the Cartographic EBR.

11. Physical properties and handling techniques of the recording film should be further investigated to minimize the effects of film dimensional changes on the registration of color separations.

12. Techniques for calibration and alignment of the electron optics of the EBR which can be readily used by operating personnel should be investigated.

13. The Vector Symbol Plot Program VSP-I should be upgraded with VSP-II, a second generation Vector Symbol Plot (VSP) Program for the IGI Electron Beam Recorder or CRT Print Head Systems. Major enhancements to the original VSP provided by IGI would be:

increased program performance
reduced program size
increased system throughput
improved human engineering

The improvements in documentation, program structure and standards are of substantial benefit for maintaining the VSP software.

Increased program performance would be achieved through elimination of non applicable processing (i.e. is it EBR or CRT). VSP-II is for the specific EBR or CRT configuration requirements. The operator may also disable graphics output to the monitor to eliminate this overhead. Overall program throughput would be limited by input data format, physical input device performance and data handling techniques.

VSP-II would provide multi buffered I/O operation for BOTH input and output. Multi buffering allows concurrent I/O and program operation. The objective of multi buffering is to eliminate the program having to wait for I/O operation completion. Benchmarks indicated that VSP-II is capable of 10-15% increased throughput over the original VSP for SVG formatted input data tapes at 800 BPI using 4000 byte average record size. Additional performance increase would be realized through program technique and organization.

14. Investigations should be conducted on the use of the new electrostatic recording films for cartographic applications. Experimental evidences indicates that excellent black and white as well as color images can be recorded with an EBR on GAF and Kodak electrostatic films.

15. Experimental investigations indicate that direct recording materials available from GAF and Kodak can form visible images upon exposure with electrons without any processing, whatsoever. These materials should be investigated and developed further for cartographic applications.

16. Electron Beam Scanner hardware and software should be added to the Cartographic EBR System. This capability would allow the Cartographic EBR to be used as both a scanner and recorder of high resolution graphics and cartographic data.

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Pre-production model cartographic EBR system

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